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Angular correlation measurements on Cu^{65}

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With 4 figures in the text

SUMMARY

The angular correlation of the two cascaded γ-rays of energies 0.38 MeV and 1.11 MeV in Cu^{65} has been studied with scintillation spectrometers.

The coefficients of the Legendre expansion $W(\theta) = 1 + A_2P_2 + A_4P_4$ of the coincidence distribution function have been determined:

$$A_2 = 0.24 \pm 0.01$$
$$A_4 = -0.01 \pm 0.01$$

The anisotropy $$A = \frac{W(\pi) - W\left(\frac{\pi}{2}\right)}{W\left(\frac{\pi}{2}\right)} = 0.41 \pm 0.02$$

The most probable spin sequence of the Cu^{65}-states is shown to be

$$7/2- \xrightarrow[M1+(E2)]{0.38} 7/2- \xrightarrow[E2]{1.11} 3/2-$$

with 1 % E2 in the 0.38 MeV-transition.

Introduction

The Ni-isotope of mass number 65 is known to decay by β-emission to Cu^{65} with a half life of 2.56^h [1, 2].

A decay scheme was proposed by Siegbahn and Ghosh [3], who made a beta spectroscopic investigation finding three beta components of energies 0.60 MeV, 1.01 MeV and 2.10 MeV. The excited levels in Cu^{65} were found to decay by γ-transitions of 0.38, 1.11 and 1.49 MeV. The 0.38 and 1.11 MeV γ-rays form a cascade with the 1.49 MeV-one as a cross-over. The angular correlation of these two γ-rays has been measured previously by Wiedling and Carlsson [4] and by Wiedling [5].

Experimental

Source

Ni^{65} was produced by a (n, γ) reaction from Ni^{64}*. The cross section of this reaction is rather low, 2 barns, and the natural abundance of Ni^{64} is only 1.2 %. To avoid

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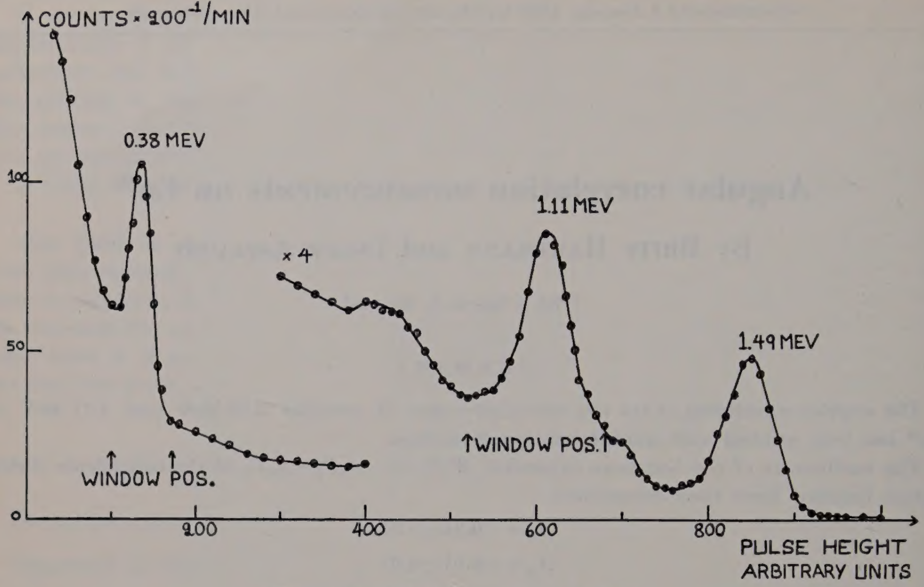

Fig. 1. Scintillation spectrum of Cu^{65}.

interference from other activities we used spec. pure nickel metal from Johnson, Matthey and Co. According to their specification the total impurity content was less than 2 parts per 10^5. The neutron flux was of the order of $3 \cdot 10^{11}$ neutrons/cm^2, sec. The time of irradiation varied from 5 to 14 hours, the long-time irradiations being made at night for practical reasons. There is no disadvantage in the long irradiation time, since the Ni^{59} and Ni^{63} activities have rather long half-lives and do not produce any γ-transitions.

For reasons mentioned above the specific activity of the Ni^{65} was not very high and the sources had to be large. They consisted of Ni-wires of 1 mm diameter with lengths ranging from 7 mm to 16 mm.

Apparatus

The electronic equipment has been described in detail by Wiedling [5]. In the Ni^{65} experiment the detectors were scintillation counters with NaI(Tl) crystals, one with 1.5″ diameter and 1.5″ length and the other with 1.5″ diameter and 1″ length. The big crystal was used in the fixed counter for recording the 1.11 MeV γ-ray and the small one in the movable counter for detecting the 0.38 MeV γ-ray. From the counters the pulses were fed into a fast-slow coincidence system, where the resolving time of the fast coincidence stage was 0.17 μsec.

Angular correlation measurements

Scintillation spectrum

A scintillation spectrum measured with the big crystal is shown in fig. 1. During the correlation measurements 2.1 mm Al were used in front of the counters in order to absorb the β-particles from the continuous β-spectrum. Single-channel

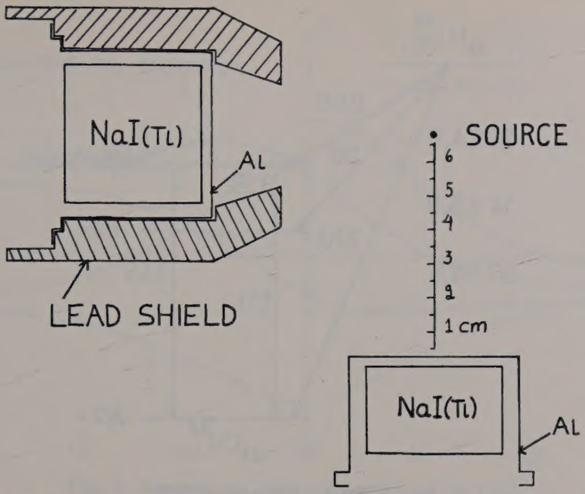

Fig. 2. Geometrical arrangement of source, crystals, and lead shield.

pulse height analyzers were used for both counters, and only the full energy photopeaks of the 0.38 MeV and 1.11 MeV γ-rays were accepted. (Fig. 1).

Scattered coincidences

The 1.49 MeV γ-ray could be expected to give rise to false coincidences due to counter-counter scattering when the measuring angle is 90°. The minimum scattering angle is then about 90°, giving a maximum scattered γ-energy of 0.38 MeV. If this scattered γ-ray is absorbed by the movable counter while the Compton electron of $1.49-0.38=1.11$ MeV is absorbed in the fixed counter a "false" coincidence will be recorded. The coincidences due to this process could be rather disturbing, especially if there is a small drift towards lower energies in the window position of the 0.38 MeV channel. To check this scattering effect, coincidences were counted in the 90°-position with a lead shield between the counters. The accidental coincidences were counted and the ratio $N_{\text{real}}/N_{\text{acc}}$ determined. The experiment was repeated without lead and the ratios (which should be independent of geometrical factors) were compared. Without lead the ratio was found to be distinctly larger than it was with lead. The difference could not be explained by source decay. To avoid disturbances from this counter to counter scattering, in the actual experiment a lead shield shaped as a cylinder + a truncate cone was placed around the crystal of the fixed counter (Fig. 2). The thickness of lead that had to be penetrated by the scattered γ-ray was nowhere less than 12 mm, which is sufficient to cut down the intensity by a factor of 32 at the maximum scattered energy of 0.38 MeV. The distance from source to counter was also increased from 50 mm to 65 mm.

The lead cone has no "smearing" effect on the directional correlation, since only the full energy photopeak of the 1.11 MeV γ-ray is accepted by the shielded counter.

Experimental runs

Several runs on different samples had to be made because of the short half-life of Ni^{65}. Coincidences were recorded automatically during 8^{m} periods for the angles 90°, 135°, 180°, 225° and 270°. The single counts in each channel were also recorded.

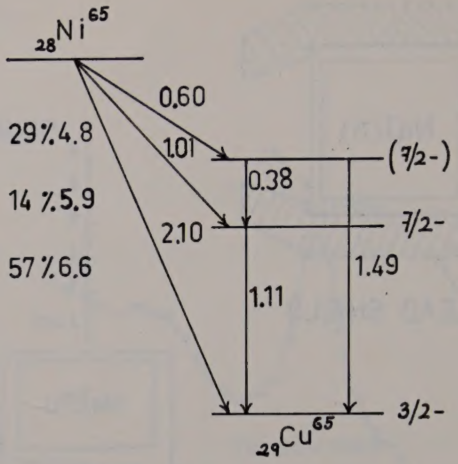

Fig. 3. Decay scheme of Ni^{65}.

The resolving time was measured during the nights by inserting a delay in one of the channels and recording coincidences and singles from a long-lived source.

Corrections

Corrections have been made for background, decay and accidental coincidences. The influence of small drifts in the channel positions was diminished by dividing the coincidence rate by the product of the singles. The corrections for finite source and detector dimensions were calculated according to a semi-empirical method given by Feingold and Frankel [6]. The efficiency curves had been determined using a collimated beam of γ-rays from Au^{198} (0.41 MeV) for the 0.38 MeV-counter and from Sc^{46} (1.12 MeV) for the 1.11 MeV counter.

Results and discussion

When the necessary corrections had been applied to the experimental coincidence rates of the different angles, the constants A_2 and A_4 in the expression $W(\theta) = 1 + A_2 P_2(\cos\theta) + A_4 P_4(\cos\theta)$ were calculated.

The values $A_2 = 0.24 \pm 0.01$

and $A_4 = -0.01 \pm 0.01$

were obtained, giving an anisotropy A of 0.41 ± 0.02. Since A_4 is rather small it is convenient in this case to use the anisotropy at least in a preliminary discussion. The discrepancy between the present anisotropy and that of references [4] and [5] is probably due to insufficient account of scattering in the earlier measurements.

The ground state spin of Cu^{65} is 3/2 [7] giving the level assignment $p\ 3/2-$. From conversion measurements in the decay of Zn^{65} Perkins and Haynes [8] concluded that the spin of the first excited state in Cu^{65} is 7/2 with a level assignment of $f\ 7/2-$. According to the results of Siegbahn and Ghosh [3] the three β-transitions in Ni^{65}

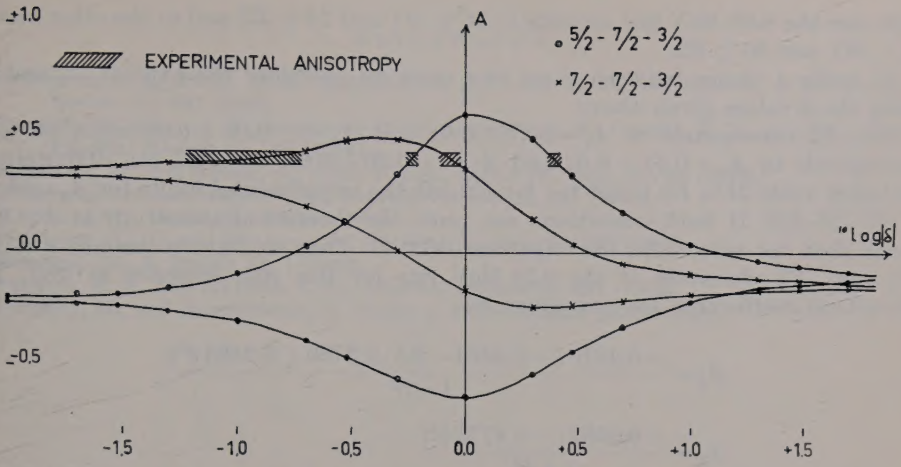

Fig. 4. Anisotropy A as a function of log | δ |.

could all be classified as allowed or first forbidden, which means that the two excited states of Cu^{65} must have the same parity as the ground state, i.e. negative. The high energy β-component is allowed but l-forbidden, $\Delta I = 1$, $\Delta l = 2$ which classifies the ground state of Ni^{65} as $f\,5/2-$. The log ft-value of the low energy β-component restricts the possible spin values of the 1.49 MeV level to 5/2 or 7/2. (Fig. 3.)

A classification of this state as $f\,5/2$ or $f\,7/2$ is compatible with the shell model. The two possibilities will now be discussed.

5/2–7/2–3/2. The 1.11 MeV-transition is classified by Perkins and Haynes [8] as mainly $E2$ with a possible small admixture of $M3$. If we assume that it is pure $E2$, a pure $M1$ character of the 0.38 MeV-transition is not consistent with the angular correlation result. The theoretical anisotropy is in this case -0.21 while the experimental one is $+0.41 \pm 0.02$. The discrepancy between theoretical and experimental anisotropy could obviously not be due to any attenuation effects, since these would not change the sign of the anisotropy (unless A_4 is very important). Further, attenuation is improbable since the half-life of an $E2$ transition of energy 1.11 MeV is probably less than 10^{-10} sec. If the 0.38 MeV-transition is a mixture of $M1$ and $E2$ with an intensity ratio $E2/M1$ of δ^2, the A_2 and A_4 can be expressed as

$$A_2 = \frac{-0.4676\,(0.3273 - 2\,\delta \cdot 0.9449 - 0.0779\,\delta^2)}{1 + \delta^2}$$

$$A_4 = \frac{-0.3582 \cdot 0.6367\,\delta^2}{1 + \delta^2}$$

using the notation of Ferentz and Rosenzweig [9]. The anisotropy is then

$$A = \frac{-0.0879\,\delta^2 + 1.23\,\delta - 0.230}{0.896\,\delta^2 - 0.442\,\delta + 1.08}$$

A is shown as a function of δ in fig. 4. There are two intersections between this curve and the experimental A-line, corresponding to $\delta = 0.57^{+0.05}_{-0.03}$ and $\delta = 2.5^{+0.3}_{-0.2}$. In the first case the 0.38 MeV line consists of 76 % $M1$ and 24 % $E2$ and in the other case of 14 % $M1$ and 86 % $E2$.

To make a choice between these two cases we calculate the explicit A_2 and A_4 using the δ-values given above.

24 % $E2$ corresponds to $A_2 = 0.27 \pm 0.01$ and $A_4 = -0.06 \pm 0.01$ while 86 % $E2$ corresponds to $A_2 = 0.31 \pm 0.02$ and $A_4 = -0.20 \mp 0.01$. 86 % $E2$ can definitely be excluded while 24 % $E2$ is not too far outside the experimental limits for A_2 and A_4.

7/2–7/2–3/2. If both transitions are pure, the theoretical anisotropy is $A = 0.34$ which does not agree with the experimental 0.41. Thus we have to assume a mixed $M1$ and $E2$ character of the 0.38 MeV line for this spin-sequence as well. The theoretical coefficients are now given by:

$$A_2 = \frac{-0.4676\,(-0.4364 - 2\,\delta \cdot 0.3780 + 0.2494\,\delta^2)}{1+\delta^2}$$

$$A_4 = \frac{-0.3582\,(-0.4775\,\delta^2)}{1+\delta^2}$$

and the anisotropy

$$A = \frac{0.306 + 0.531\,\delta - 0.165\,\delta^2}{0.898 - 0.177\,\delta + 1.12\,\delta^2}$$

A is shown as a function of δ in fig. 4. Intersections with the experimental A-line are now given by $\delta = 0.11^{+0.07}_{-0.05}$ and $\delta = 0.83^{+0.13}_{-0.09}$ giving an $E2$-admixture of 1 % and 41 % respectively. 1 % $E2$ gives $A_2 = 0.24 \pm 0.02$ and $A_4 = 0.002^{+0.003}_{-0.001}$ while 41 % $E2$ gives $A_2 = 0.25^{+0.01}_{-0.02}$ and $A_4 = 0.07 \pm 0.01$.

Both A_2 values show good agreement with the experimental one. Thus we have to discuss A_4. The calculated A_4 is always positive while the experimental A_4 is negative. With 1 % $E2$, however, the positive A_4 is very small. Due to the low accuracy of the experimental value, a small positive A_4 is quite possible. Thus it seems to be most probable that the 0.38 MeV-transition is mainly $M1$ with a 1 % $E2$ admixture, provided the spin of the 1.49-state is 7/2.

The possibility of $M3$-admixture in the 1.11 MeV-transition suggested by Perkins and Haynes [8] has not been considered, partly because such a mixture if present must be very small and partly because it is not possible to discuss it unless A_4 is very accurate, or accurate conversion data for the 0.38 MeV and 1.11 MeV-transitions are available.

No further information can be obtained from a discussion of the relative intensities of the 0.38 MeV and 1.49 MeV-line, since the theoretical transition probabilities are not at present accurate enough. It can be said, however, that an $E2$ character of the 1.49 MeV γ ray and a $M1$ character of the 0.38 MeV γ-ray are quite compatible with the relative γ-intensities stated by Siegbahn and Ghosh [3], and those estimated from the scintillation spectrum.

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